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RESEARCH MEMORANDUM

COMPONENT OPERATING TRENDS DURING ACCELERATION AND DECELERATION OF TWO HYPOTHETICAL TWO-SPOOL TURBOJET ENGINES

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON
April 21, 1955

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COMPONENT OPERATING TRENDS DURING ACCELERATION AND DECELERATION OF TWO HYPOTHETICAL TWO-SPOOL TURBOJET ENGINES

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SUMMARY

The compressor and turbine operating trends during acceleration and deceleration of two hypothetical two-spool turbojet engines are investigated. The two engines are characterized by the same component performance maps, but the arbitrarily specified ratio of outer- to inner-spool moment of inertia for the second engine is 4 times that specified for the first engine. For static sea-level operation and assigned values of exhaust-nozzle area and inner-turbine inlet temperature, transient paths of the compressor and turbine components and speed variations of the outer and inner spools are found for the two engines.

The calculations indicate that surging of the outer or the inner compressor may be encountered during acceleration and that, for the engine having the greater outer- to inner-spool moment-of-inertia ratio, surging of the outer compressor is possible during deceleration. Increasing the ratio of outer-spool to inner-spool moment of inertia by a factor of 4 resulted in an increase in the inner-spool overspeeding from 0.4 to 2.2 percent at the end of the calculated acceleration. The design values of inner- and outer-turbine equivalent specific work were not exceeded during acceleration or deceleration.

INTRODUCTION

In order to evaluate the operating characteristics and design problems of two-spool engines, an analytical study of two-spool aircraft engines is now being conducted at the NACA Lewis laboratory. When the operating characteristics of the engine components are known, two-spool matching procedures, such as those presented in reference 1, may be applied to obtain the equilibrium and transient performance of turbojet and turboprop engines in which various amounts of bleed and power are extracted from the engine components. The matching process is employed in reference 1 to investigate for sea-level static conditions the equilibrium operation of a hypothetical two-spool turbojet engine in which the compressor and turbine performances are based on experimental results.

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The effect of design over-all compressor-pressure-ratio division on two-spool turbojet-engine performance and geometry is determined in reference 2 by considering three engines, each having the same design values of over-all compressor pressure ratio, turbine-inlet temperature, and afterburner temperature but different divisions of over-all compressor pressure ratio between the outer and inner compressors.

The objective of the present report is to study the compressor and turbine operating trends during acceleration and deceleration of two hypothetical two-spool turbojet engines. Determination of compressor 3568
trends will indicate whether or not surge may be initiated by the outer or inner compressor during transient engine operation. If surge difficulties are anticipated before an engine is designed, the design operating points of the components may possibly be selected so that the compressor surge problem during transient operation is alleviated. If it is found that either the outer- or inner-turbine equivalent specific work exceeds the design value during transient operation, sufficient equivalent-specific-work margin may be provided by selecting a conservative design value for the turbine-exit axial-velocity ratio. In so doing, the time required to accelerate will not be needlessly lengthened because one of the turbines operates at its limiting-loading condition. Another problem to be considered during the transient operation of a two-spool engine is the mechanical speed relation between the outer and inner spools. For a specific engine, serious stress problems might arise during a transient if the speed of either spool greatly exceeds its design value.

In this report, two hypothetical two-spool turbojet engines, herein designated engines A and B, are considered. Each of these engines is characterized by the component performance maps discussed in reference 1. The difference between the engines is that the arbitrarily specified ratio of outer- to inner-spool moment of inertia for engine B is 4 times that specified for engine A, the ratio for engine A being realistic for the work split. For static sea-level operation and assigned values of exhaust-nozzle area and inner-turbine inlet temperature, transient-operation paths are calculated and plotted on each of the compressor and turbine component maps. The variations of inner- and outer-spool mechanical speed with time are found for the two engines.

METHOD OF ANALYSIS

Engines

The hypothetical two-spool turbojet engines considered in this report employ the component-performance characteristics discussed in reference 1. The compressor and turbine component performance maps, which are presented in figure 1 in terms of the conventional rating parameters, are based on various compressor and turbine data determined experimentally at the NACA Lewis laboratory. The design-point conditions are as follows:

Over-all compressor total-pressure ratio	10.4
Outer-compressor equivalent weight flow, lb/sec	48
Outer-compressor total-pressure ratio	2.6
Outer-compressor efficiency, percent	82
Inner-compressor total-pressure ratio	4.0
Inner-compressor efficiency, percent	83.7
Inner-turbine inlet temperature, $^{\circ}R$	2074
Inner-turbine equivalent specific work, Btu/lb	24.1
Inner-turbine efficiency, percent	84
Outer-turbine equivalent specific work, Btu/lb	13.9
Outer-turbine efficiency, percent	88.5
Exhaust-nozzle area, sq ft	0.667

The moments of inertia of the two spools were not pertinent to the equilibrium performance discussion in reference 1. They are relevant, however, to the transient performance discussed in this report. The moments of inertia of the outer and inner spools of engine A are assigned arbitrarily to be 1 and 2(lb)(ft)(sec^2), respectively, while those of engine B are assigned to be 2 and 1(lb)(ft)(sec^2), respectively. The moment-of-inertia values for engine A are believed to be realistic for an engine composed of components with the performances shown in figure 1. It is unlikely that the ratio of outer- to inner-spool moment of inertia may vary by a factor of 4 for a given set of component performance maps. Such a variation is considered, however, to indicate the effect of this ratio on component operating trends during acceleration and deceleration.

Transients Considered

For each engine, an acceleration and a deceleration were considered for static sea-level operation with design exhaust-nozzle area. From the data of reference 1 for static sea-level operation with design exhaust-nozzle area and no bleed, the equilibrium conditions at 50 and 100 percent of design thrust were found to be as follows:

Equilibrium values	Percent design thrust	
	50	100
Inner-turbine inlet temperature, T_4, $^{\circ}R$	1651	2074
Outer-spool equivalent speed, $N_o/\sqrt{\theta_1}$, percent design	85.7	100
Inner-spool equivalent speed, $N_i/\sqrt{\theta_1}$, percent design	90.1	100
Inner-compressor equivalent speed, $N_i/\sqrt{\theta_2}$, percent design	92.9	100

The acceleration was considered to start with each of the components operating at its equilibrium conditions for 50-percent design thrust. An instantaneous increase in inner-turbine inlet temperature (at constant outer- and inner-spool speeds) from the equilibrium value of 1651° R to an arbitrarily selected value of 2300° R was assumed to initiate the acceleration. Inner-turbine inlet temperature was assumed to be held constant at 2300° R during the entire acceleration, which continued until the outer spool reached its design speed. Upon attainment of outer-spool design speed, it was assumed that the acceleration could be terminated by an instantaneous decrease in temperature from 2300° R to the 3568
equilibrium design temperature of 2074° R. The acceleration, therefore, was terminated before the two spools reached the equilibrium that would exist at 2300° R. Initiation of accleration by means of a step increase in temperature represents an extreme condition and serves to emphasize component trends.

At the beginning of the deceleration, each component operated at its equilibrium conditions for 100-percent design thrust. An instantaneous decrease in inner-turbine inlet temperature (at constant outer- and inner-spool speeds) from the design value of 2074° R to an arbitrarily selected value of 1500° R was assumed to initiate the deceleration. During the entire deceleration, inner-turbine temperature was assumed to be held constant at 1500° R. When the outer-spool speed attained its 50-percent-thrust equilibrium value, it was assumed that the decerlation could be terminated by an instantaneous increase in temperature from 1500° R to the 50-percent-thrust equilibrium temperature of 1651° R. The decerlation, therefore, was terminated before the two spools reached the equilibrium that would exist at 1500° R.

Calculation Procedure

The component performance maps (fig. 1) for equilibrium operation are assumed to be valid for transient operation. At the beginning of a transient, the outer- and inner-spool equivalent speeds are assumed to be the equilibrium values. These values of speed, together with the assigned values of inner-turbine inlet temperature and exhaust-nozzle area, fix the operation of each of the components. The values of excess torque acting on each spool permit the calculation of the speed increments for a finite time interval. The new values of outer- and inner-spool speed, together with the specified values of inner-turbine inlet temperature and exhaust-nozzle area, determine the operation of each of the components at the new time. The process is repeated until the desired value of outer-spool equivalent speed is attained. Symbols are defined in appendix A, and details of the calculation procedure are discussed in appendix B.

RESULTS AND DISCUSSION

Acceleration Characteristic

Component operating trends. - The equilibrium and acceleration paths for engines A and B are plotted on the compressor and turbine component performance maps in figure 2. At the beginning of the acceleration, it is assumed that the inner-turbine inlet temperature is 2300° R and that the values of $N_O/\sqrt{\theta_1}$ and $N_I/\sqrt{\theta_1}$ are equal to their equilibrium values at 50-percent design thrust. Therefore, the component operating points of engines A and B at the initial time are independent of the assigned values of moment of inertia. At the initial time, the outer-compressor operating points of engines A and B jump instantaneously from the equilibrium point a to point b near the outer-compressor stall-limit line (fig. 2(a)). This jump corresponds to the instantaneous increase in inner-turbine inlet temperature at constant outer- and inner-spool speeds. The instantaneous increase in combustor temperature is accompanied by a slight decrease in over-all compressor pressure ratio and a large decrease in outer-compressor equivalent weight flow, so that inner-turbine equivalent weight flow remains constant at its choked value. After the initial time, component operation is dependent on the moments of inertia of the two spools, so that the transient paths of engine A differ from those of engine B. The outer-compressor acceleration path of engine A (b to c, fig. 2(a)) lies between the stall-limit line and the equilibrium path (a to d), while that of engine B (b tc c') crosses the equilibrium path.

Excluding the initial point then, at a given outer-compressor equivalent speed, engine B operates at a higher value of outer-compressor equivalent weight flow than engine A. The inner-spool moment of inertia of engine B being less than that for engine A, the inner spool of engine B speeds up faster during an acceleration, so that the inner-compressor of engine B requires more equivalent weight flow from the outer compressor than does the inner compressor of engine A. For the specific engines considered herein, the demands of engine B are such that its acceleration path on the outer-compressor performance map lies partly on the high-weight-flow side of the equilibrium path.

At the beginning of the acceleration, the inner-compressor operating points of engines A and B jump instantaneously from the equilibrium point a to point b on the inner-compressor stall-limit line (fig. 2(b)). The increase in temperature ratio across the combustor is accompanied by a decrease in equivalent weight flow at the inner-compressor exit, so that inner-turbine equivalent weight flow remains constant. Since there is only a small change in inner-compressor equivalent speed $N_I/\sqrt{\theta_2}$, the equivalent weight flow at the inner-compressor inlet also decreases from its equilibrium value.

At the beginning of the acceleration then, both the outer and the inner compressors move from their equilibrium operating points toward their stall-limit lines. In engines A and B, the inner-compressor initiates surge. For other engines, it is quite possible for the outer compressor to initiate surge during acceleration. For example, if the outer-compressor stall-limit line of engines A and B occurred at higher values of equivalent weight flow, the outer compressor could have initiated surge. The inner-compressor acceleration paths of engines A and B lie between the stall-limit line and the equilibrium path (fig. 2(b)). Since the inner-spool moment of inertia is smaller for engine B than for engine A, the inner compressor of engine B attains a higher value of equivalent speed than that of engine A during the acceleration. 3568

The calculations show that, during acceleration, both the outer and the inner turbines are limited to values of equivalent specific work and equivalent speed less than the design values (fig. 2(c) and (d)). Thus, turbine limiting loading will not be encountered during acceleration, and neither the outer nor the inner turbine need be conservatively designed to provide equivalent-specific-work margin during acceleration. This applies to engines A and B, since their acceleration paths differ only slightly.

Speed variations. - The variations of outer-spool equivalent speed $N_o/\sqrt{\theta_1}$ and inner-spool equivalent speed $N_i/\sqrt{\theta_1}$ with time are shown in figure 3. Because static sea-level conditions were specified, these variations are also the outer- and inner-spool mechanical speed variations. The outer and inner spools of engine A reach their design-speed values at about the same time (fig. 3(a)). When the outer spool of engine A attains its design value of equivalent speed, the inner-spool is operating at 100.4 percent of its design equivalent speed. The inner and outer spools of engine B reach their design values of equivalent speed at 0.66 and 1.15 seconds, respectively (fig. 3(b)). However, when the outer-spool equivalent speed is 100 percent of design, the inner-spool equivalent speed is 102.2 percent of design. Thus, increasing the ratio of outer- to inner-spool moment of inertia by a factor of 4 results in an increase in inner-spool overspeeding from 0.4 to 2.2 percent at the end of the calculated acceleration. This result is also shown in figure 4, which is a plot of inner-spool equivalent speed against outer-spool equivalent speed. During acceleration, the speed relation for engine A, which was assigned realistic values of outer- and inner-spool moments of inertia, differs only slightly from that for equilibrium operation. For engine B, however, over most of the outer-spool speed range, the inner-spool speed values are 2 to 3 percent higher than those for equilibrium operation.

Deceleration Characteristics

Component operating trends. - The equilibrium and deceleration paths for engines A and B are plotted on the component performance maps in figure 5. At the beginning of the deceleration, the outer compressor moves from its equilibrium operating point a to point b away from its stall-limit line (fig. 5(a)). The instantaneous decrease in combustor temperature is accompanied by a decrease in over-all compressor pressure ratio and an increase in outer-compressor equivalent weight flow. (Inner-turbine equivalent weight flow remains constant.) The deceleration path of engine A lies entirely on the high-weight-flow side of the equilibrium path. The deceleration path of engine B however, crosses the equilibrium path and approaches outer-compressor surge.

Since the inner-spool moment of inertia of engine B is less than that for engine A, the inner spool of engine B slows down faster during a decleration, so that, at a given outer-spool speed, the inner compressor of engine B requires less equivalent weight flow from the outer compressor than does the inner compressor of engine A. For the specific engines considered herein, the demands of engine B are such that its deceleration path on the outer-compressor performance map lies in part on the low-weight-flow side of the equilibrium path. This indicates that surging the outer compressor during deceleration may be possible for engines having an outer-spool moment of inertia much larger than the inner-spool moment of inertia.

At the beginning of decleration, the inner-compressor jumps from its equilibrium operating point a to point b away from the inner-compressor stall-limit line (fig. 5(b)). Because the inner-turbine equivalent weight flow remains constant, the instantaneous decrease in temperature ratio across the combustor is accompanied by an increase in equivalent weight flow at the inner-compressor outlet. Since inner-compressor equivalent speed $N_i/\sqrt{\theta_2}$ increases slightly, the increase in outlet equivalent weight flow is accompanied by an increase in equivalent weight flow at the inner-compressor inlet. The deceleration paths of engines A and B lie on the high-weight-flow side of the equilibrium path. The inner-spool moment of inertia being smaller for engine B than for engine A, the inner compressor of engine B attains a lower value of equivalent speed during the deceleration than that of engine A.

Operation of the inner turbine during deceleration (fig. 5(c)) takes place at equivalent speeds higher than design and at equivalent-specific-work values lower than design. The ratio of outer- to inner-spool moment of inertia has only a slight effect on inner-turbine operation. During deceleration, the outer turbine (fig. 5(d)) also operates at equivalent speeds higher than design and at equivalent-specific-work values lower than design. During the latter part of the deceleration, the outer-turbine equivalent-specific-work values of engine B are lower than those for engine A.

Speed variations. - The variations of outer- and inner-spool equivalent speeds with time are shown in figure 6. For engine A (fig. 6(a)),

the outer- and inner-spool speeds for equilibrium operation at 50-percent design thrust are reached at about the same time. When the outer-spool speed of engine A reaches its equilibrium value, the inner-spool speed is 90.3-percent design, the equilibrium value being 90.1 percent design. The inner and outer spools of engine B reach their equilibrium values in 0.34 and 0.78 second, respectively (fig. 6(b)). When the outer-spool speed decreases to its value for equilibrium operation at 50-percent design thrust, the inner-spool speed is 86.8-percent design instead of 90.1-percent design, the equilibrium value. Increasing the ratio of outer- to inner-spool moment of inertia by a factor of 4 3568
results in an increase in inner-spool underspeeding from -0.2 to 3.3 percent at the end of the calculated deceleration. The variation of inner-spool equivalent speed with outer-spool equivalent speed is shown in figure 7. During deceleration the speed relation for engine A, which was assigned realistic values of outer- and inner-spool moments of inertia, is the same as for equilibrium operation. For engine B, however, at each value of outer-spool speed, the inner-spool speed during deceleration is lower than that for equilibrium operation.

SUMMARY OF RESULTS

The following results were obtained from transient studies for two hypothetical two-spool turbojet engines. The two engines are characterized by the same component performance maps, but the arbitrarily specified ratio of outer- to inner-spool moment of inertia for the second engine is 4 times that specified for the first engine.

1. During acceleration, surging of either the outer or the inner compressor may be encountered.

2. The calculations for the engine having the greater outer- to inner-spool moment-of-inertia ratio indicated that surging of the outer compressor is possible during deceleration.

3. An increase in the ratio of outer- to inner-spool moment of inertia by a factor of 4 resulted in an increase in inner-spool overspeeding from 0.4 to 2.2 percent at the end of the calculated acceleration.

4. The design values of inner- and outer-turbine equivalent specific work were not exceeded during acceleration or deceleration.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, December 17, 1954

APPENDIX A

SYMBOLS

The following symbols are used in this report:

A area, sq ft

c_p specific heat at constant pressure, Btu/(lb)($^{\circ}$R)

f fuel-air ratio at combustor inlet

H stagnation enthalpy, Btu/lb

I moment of inertia, (lb)(ft)(sec^2)

N rotational speed, rps

P total pressure, lb/sq ft

p static pressure, lb/sq ft

Q excess torque, lb ft

T total temperature, $^{\circ}$R

t time, sec

W weight flow, lb/sec

η adiabatic efficiency

θ ratio of total temperature to NACA standard sea-level temperature, $T/518.7$

δ ratio of total pressure to NACA standard sea-level pressure, $P/2116$

Subscripts:

i inner spool

o outer spool

0 ambient conditions

1 outer-compressor inlet

2 outer-compressor exit, inner-compressor inlet

3 inner-compressor exit, combustor inlet

4 combustor exit, inner-turbine inlet

5 inner-turbine exit, outer-turbine inlet

6 outer-turbine exit, tail-pipe inlet

7 exhaust-nozzle exit

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APPENDIX B

MATCHING PROCEDURE FOR TRANSIENT OPERATION

Transient performance for static sea-level conditions was calculated with the assumption of isentropic flow in the engine inlet and downstream of the outer turbine through a constant-area convergent nozzle. The component performance valid for equilibrium operation was assumed to be valid for operation during acceleration and deceleration. In matching the components for transient operation, constant values of fuel-air ratio and burner pressure ratio P_4/P_3 were used. At the beginning of a transient, the inner- and outer-spool equivalent speeds were assumed to be the equilibrium values.

Compressor Operation

The values of outer- and inner-spool equivalent speed, inner-turbine inlet temperature, and exhaust-nozzle area are specified at the initial time. The outer- and inner-compressor operating points are found in an indirect manner. A trial value of $W_2\sqrt{\theta_2}/\delta_2$ is selected. The operating point of the outer compressor is fixed by the values of $W_2\sqrt{\theta_2}/\delta_2$ and $N_o/\sqrt{\theta_1}$. A value of $N_i/\sqrt{\theta_2}$ is calculated which, together with the value of $W_2\sqrt{\theta_2}/\delta_2$, fixes the inner-compressor operating point. A value of T_4 is calculated from

$$T_4 = T_1 \left[\frac{W_4\sqrt{\theta_4}}{\delta_4} \, \frac{\left(\frac{P_3}{P_2}\right)\left(\frac{P_4}{P_3}\right)\sqrt{\frac{T_2}{T_1}}}{(1 + f)\,\frac{W_2\sqrt{\theta_2}}{\delta_2}} \right]^2 \tag{1}$$

where the value of $W_4\sqrt{\theta_4}/\delta_4$ is assumed to be the design value. (The validity of this assumption may be checked when the inner-turbine operating point is found.) If the value of T_4 calculated from equation (1) does not equal the assigned T_4 value, a new value of $W_2\sqrt{\theta_2}/\delta_2$ is selected. The process is repeated until the calculated T_4 agrees with the assigned T_4.

Turbine Operation

The inner-turbine equivalent speed $N_i/\sqrt{\theta_4}$ may be calculated from the known values of $N_i/\sqrt{\theta_1}$ and T_4/T_1. The operating points of the inner and outer turbines are found in an indirect manner. A trial value of P_4/P_6 is selected. If the proper value is chosen, the value of exhaust-nozzle area calculated later in the procedure will check with the specified value of A_7. Before the selected value of P_4/P_6 can be checked, a value of inner-turbine pressure ratio P_4/P_5 is selected. A tentative operating point for the inner turbine is thereby fixed by the values of P_4/P_5 and $N_1/\sqrt{\theta_4}$ so that the inner-turbine temperature ratio T_4/T_5 may be found. Outer-turbine values of equivalent speed, pressure ratio, and flow parameter may be calculated from

3568

$$\frac{N_o}{\sqrt{\theta_5}} = \frac{N_o}{\sqrt{\theta_1}} \frac{\sqrt{\frac{T_4}{T_5}}}{\sqrt{\frac{T_4}{T_1}}} \tag{2}$$

$$\frac{P_5}{P_6} = \frac{\frac{P_4}{P_6}}{\frac{P_4}{P_5}} \tag{3}$$

$$\frac{W_5 N_o}{\delta_5} = \frac{W_1\sqrt{\theta_1}}{\delta_1} \frac{N_o}{\sqrt{\theta_1}} \frac{(1 + f)}{\frac{P_2}{P_1}\left(\frac{P_3}{P_2}\right)\frac{P_4}{P_3}\left(\frac{P_5}{P_4}\right)} \tag{4}$$

The outer-turbine values of $N_o/\sqrt{\theta_5}$ and P_5/P_6 fix outer-turbine operation and a value of W_5N_o/δ_5 may be read from an appropriate plot. If this value of flow parameter does not equal the value calculated from equation (4), a new value of inner-turbine pressure ratio P_4/P_5 is selected. The process is repeated until the two values of flow parameter agree. When this is accomplished the tentative operating points of the inner and outer turbines are known. From the values of $N_o/\sqrt{\theta_5}$ and P_5/P_6 and an appropriate plot, the outer-turbine temperature ratio T_6/T_5 is read.

An exhaust-nozzle area value is found from values of $W_7\sqrt{\theta_7}/\delta_7$ and $W_7\sqrt{\theta_7}/\delta_7 A_7$. The value of nozzle equivalent weight flow is calculated from

$$\frac{W_7\sqrt{\theta_7}}{\delta_7} = \frac{W_1\sqrt{\theta_1}}{\delta_1} \frac{(1 + f)\sqrt{\frac{T_7}{T_1}}}{\frac{P_7}{P_1}} \tag{5}$$

The nozzle equivalent specific weight flow is found from the value of P_7/p_0 and appropriate tables. If the calculated value of A_7 does not equal the specified value, a new value of P_4/P_6 is selected. The procedure is repeated until the selection of P_4/P_6 is found to be compatible with the specified exhaust-nozzle area.

3568

Excess Torque Values

The excess torques available for accelerating the outer and inner spools are calculated from

$$Q_o = \frac{778W_1}{2\pi N_o}\left[(1 + f)\ c_{p,5}T_5\left(1 - \frac{T_6}{T_5}\right) - c_{p,1}T_1\left(\frac{T_2}{T_1} - 1\right)\right] \tag{6}$$

$$Q_i = \frac{778W_1}{2\pi N_i}\left[(1 + f)\ c_{p,4}T_4\left(1 - \frac{T_5}{T_4}\right) - c_{p,2}T_2\left(\frac{T_3}{T_2} - 1\right)\right] \tag{7}$$

Trial increments in N_o and N_i are defined by the following equations:

$$\Delta N_o = \frac{Q_o}{2\pi I_o}\Delta t \tag{8}$$

$$\Delta N_i = \frac{Q_i}{2\pi I_i}\Delta t \tag{9}$$

where the value of Δt is specified. At time equal to the initial time plus the time increment, trial values of N_o and N_i are defined to be equal to initial values of N_o and N_i plus the incremental values from equations (8) and (9). For these trial values of N_o and N_i and the specified values of T_4 and A_7, the calculation is repeated to yield the component operating points and excess torque values acting on the outer and inner spools. The actual increments in N_o and N_i are found by substituting in equations (8) and (9) average values of Q_o and Q_i, which are defined to be the arithmetic means of the values corresponding to the initial and trial values of N_o and N_i. The actual values of N_o and N_i at time equal to the initial time plus the time increment are equal to the initial values of N_o and N_i plus the actual speed increments.

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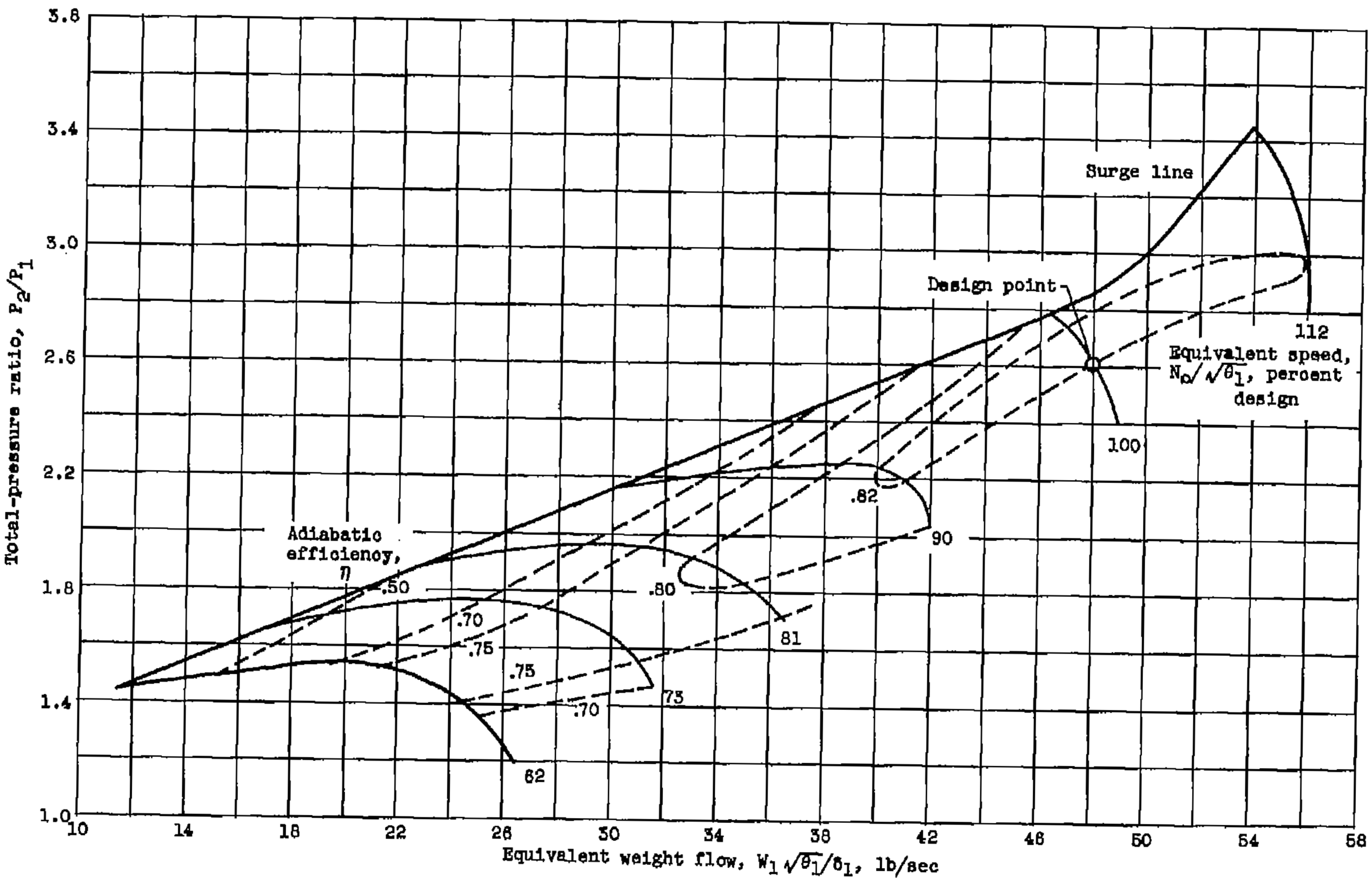
2. Dugan, James F., Jr.: Effect of Design Over-All Compressor Pressure Ratio Division on Two-Spool Turbojet-Engine Performance and Geometry. NACA RM E54F24a, 1954.



(a) Outer compressor.

Figure 1. - Component performance maps.

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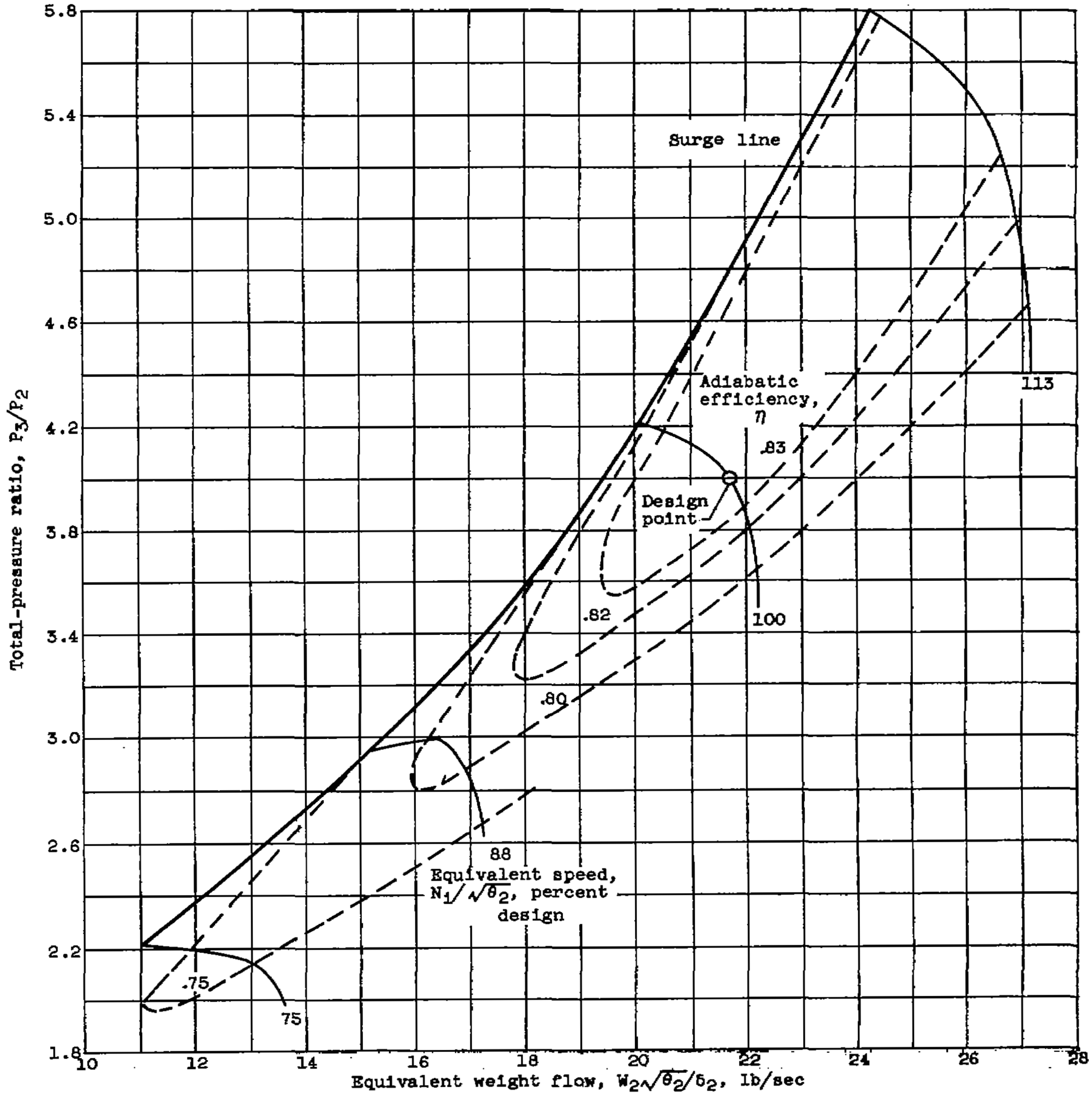

(b) Inner compressor.

Figure 1. - Continued. Component performance maps.

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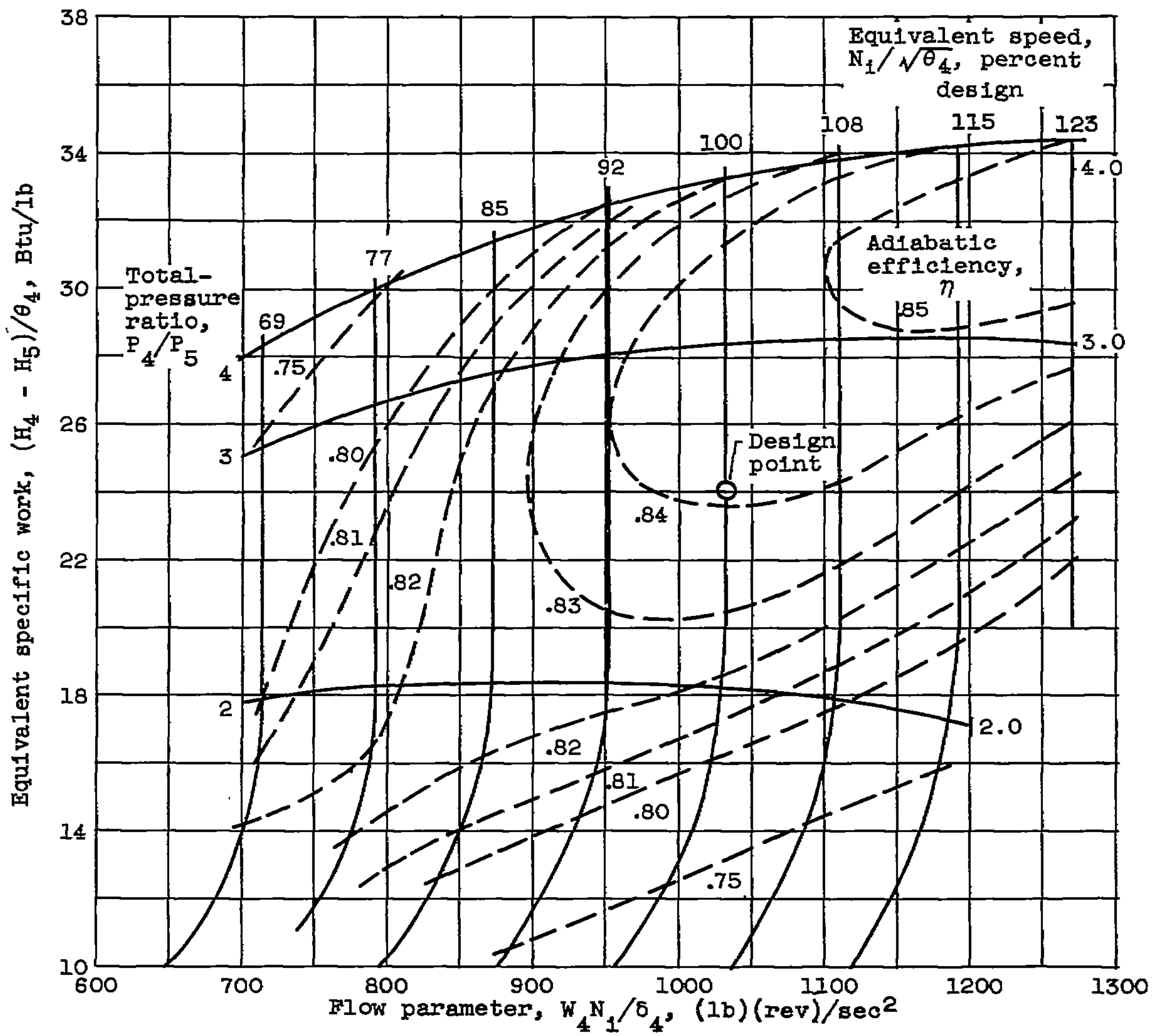

(c) Inner turbine.

Figure 1. - Continued. Component performance maps.

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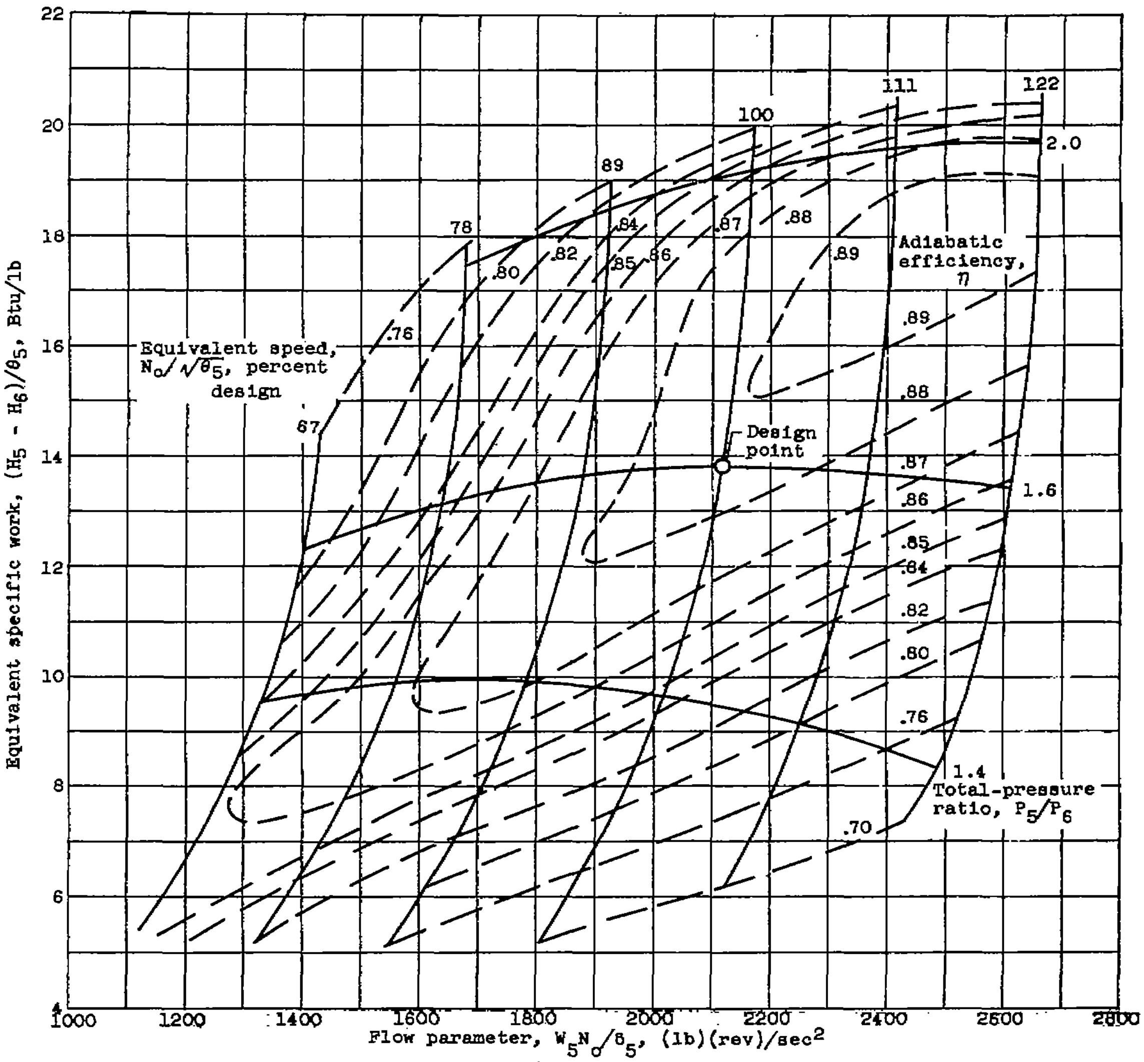

(d) Outer turbine.

Figure 1. - Concluded. Component performance maps.

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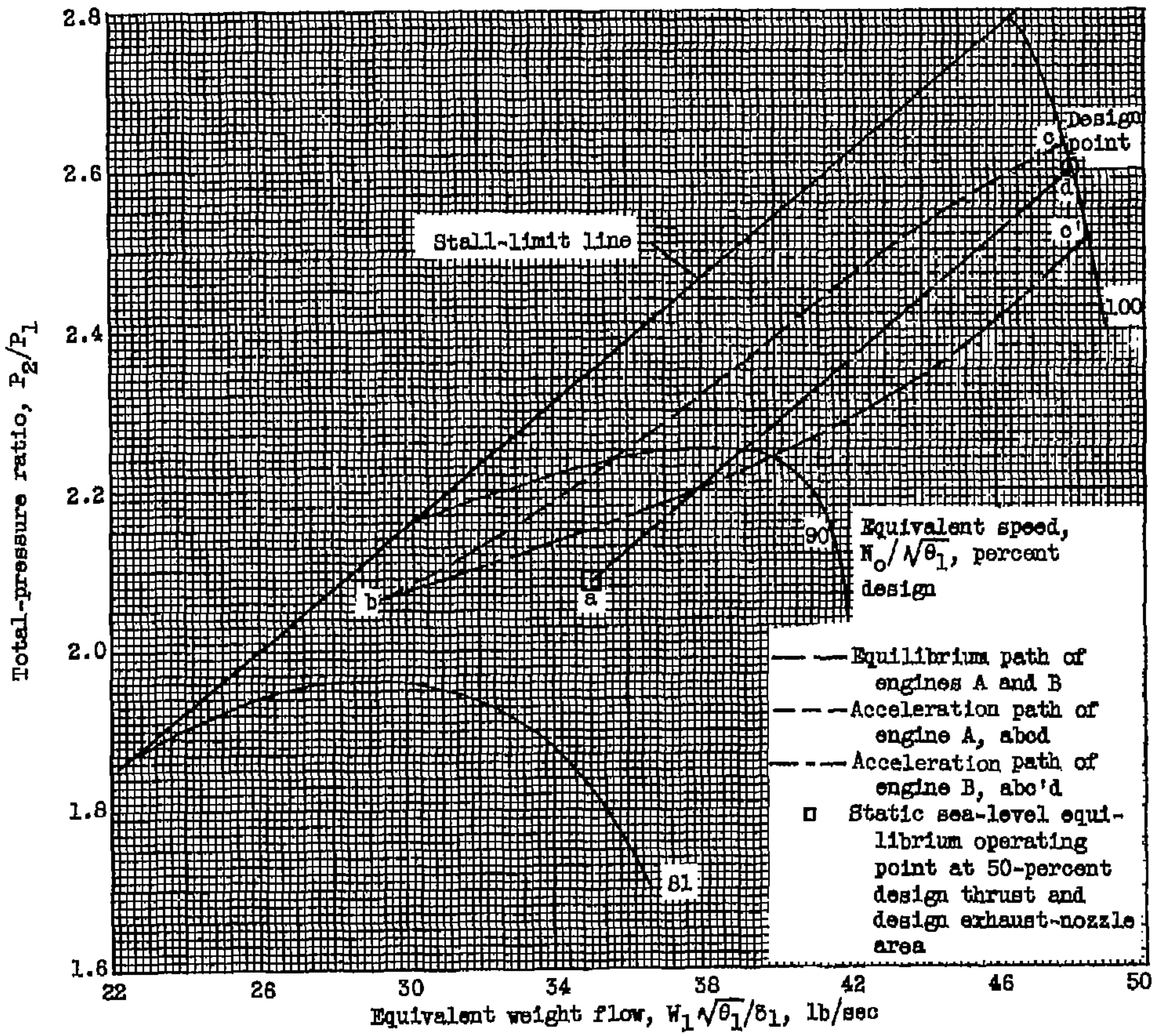

(a) Outer compressor.

Figure 2. - Equilibrium and acceleration paths for engines A and B.

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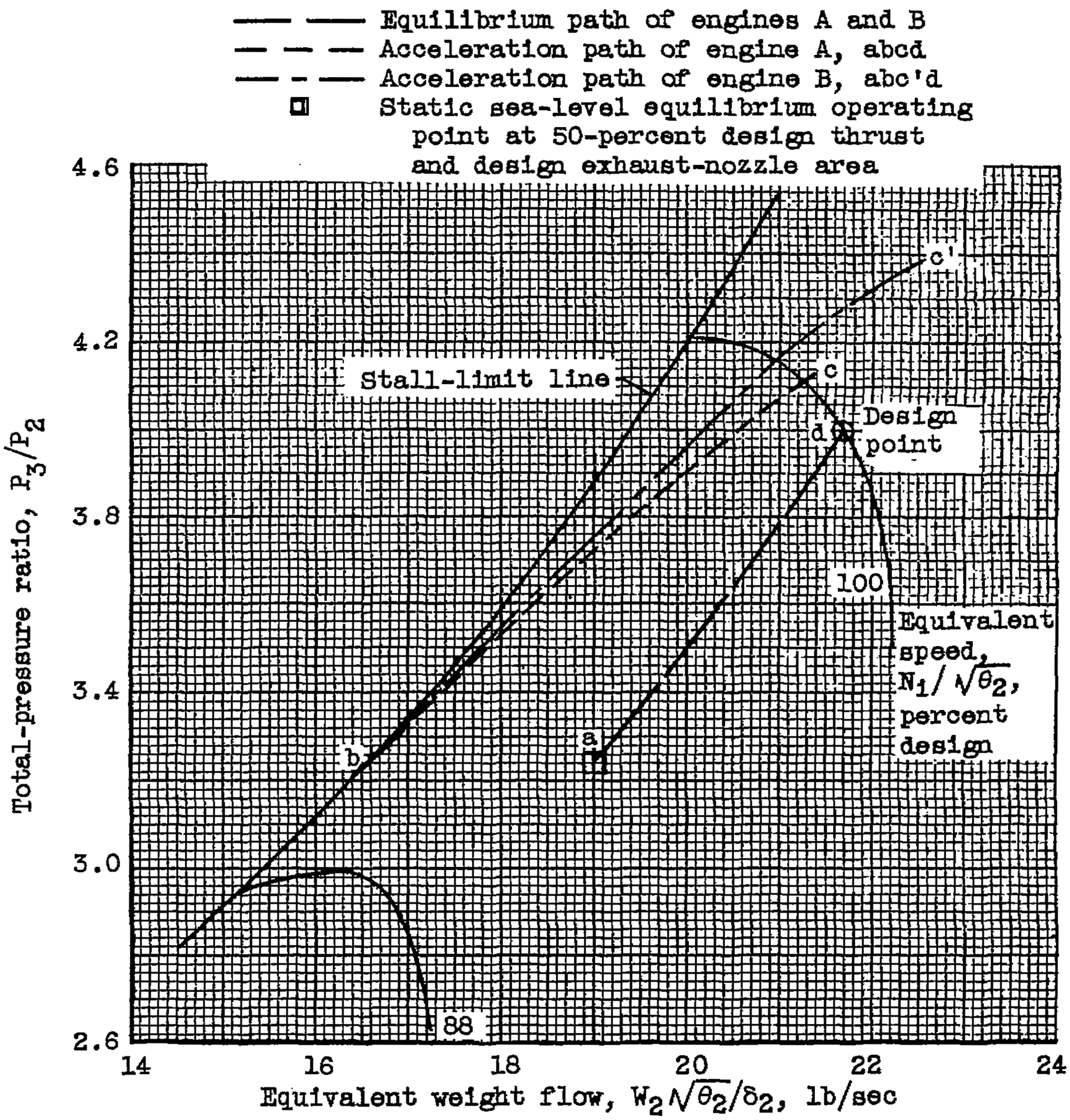

(b) Inner compressor.

Figure 2. - Continued. Equilibrium and acceleration paths for engines A and B.

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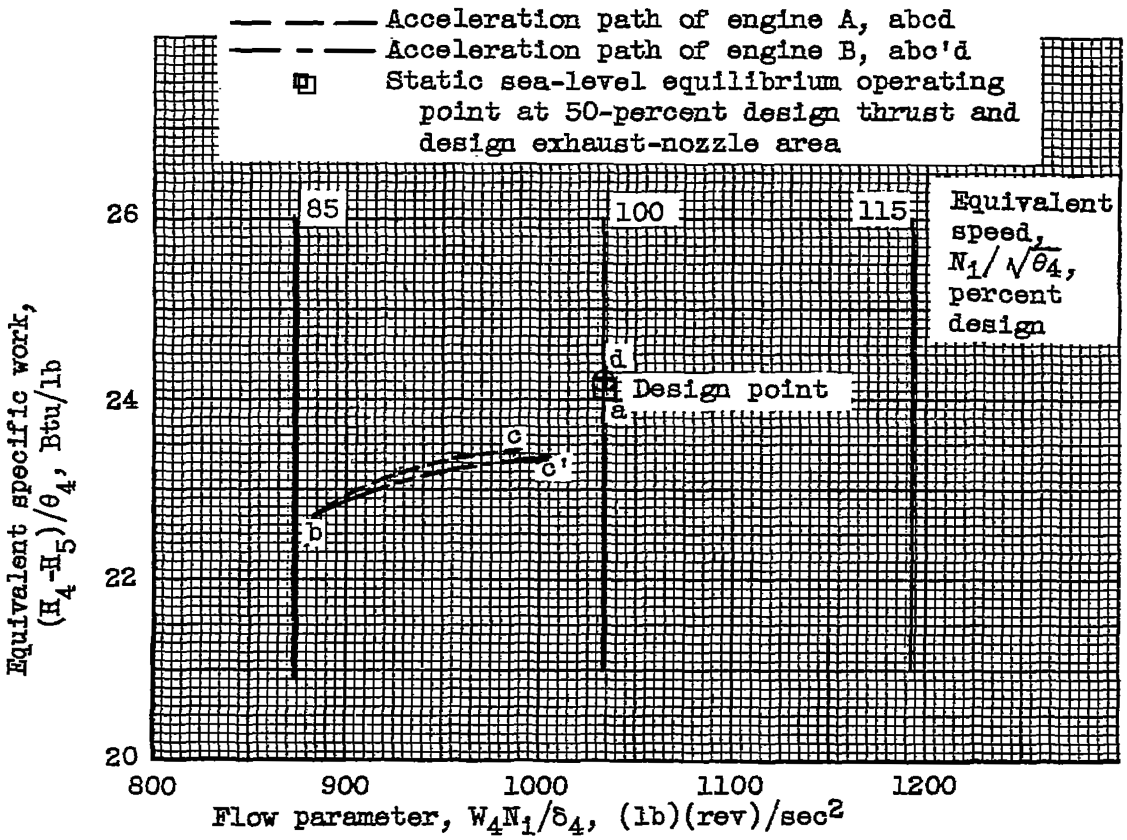

(c) Inner turbine.

Figure 2. - Continued. Equilibrium and acceleration paths for engines A and B.

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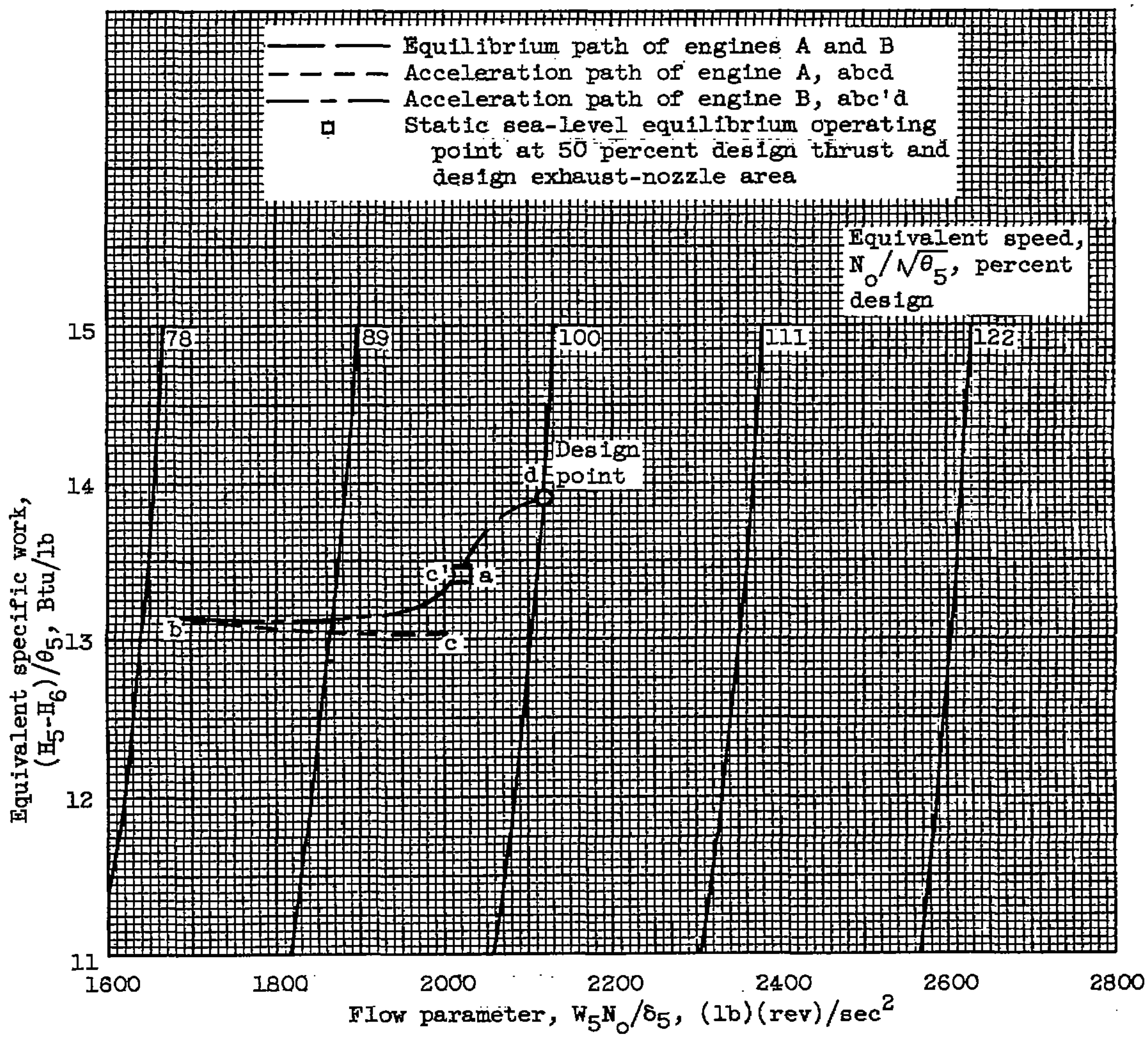

(d) Outer turbine.

Figure 2. - Concluded. Equilibrium and acceleration paths for engines A and B.

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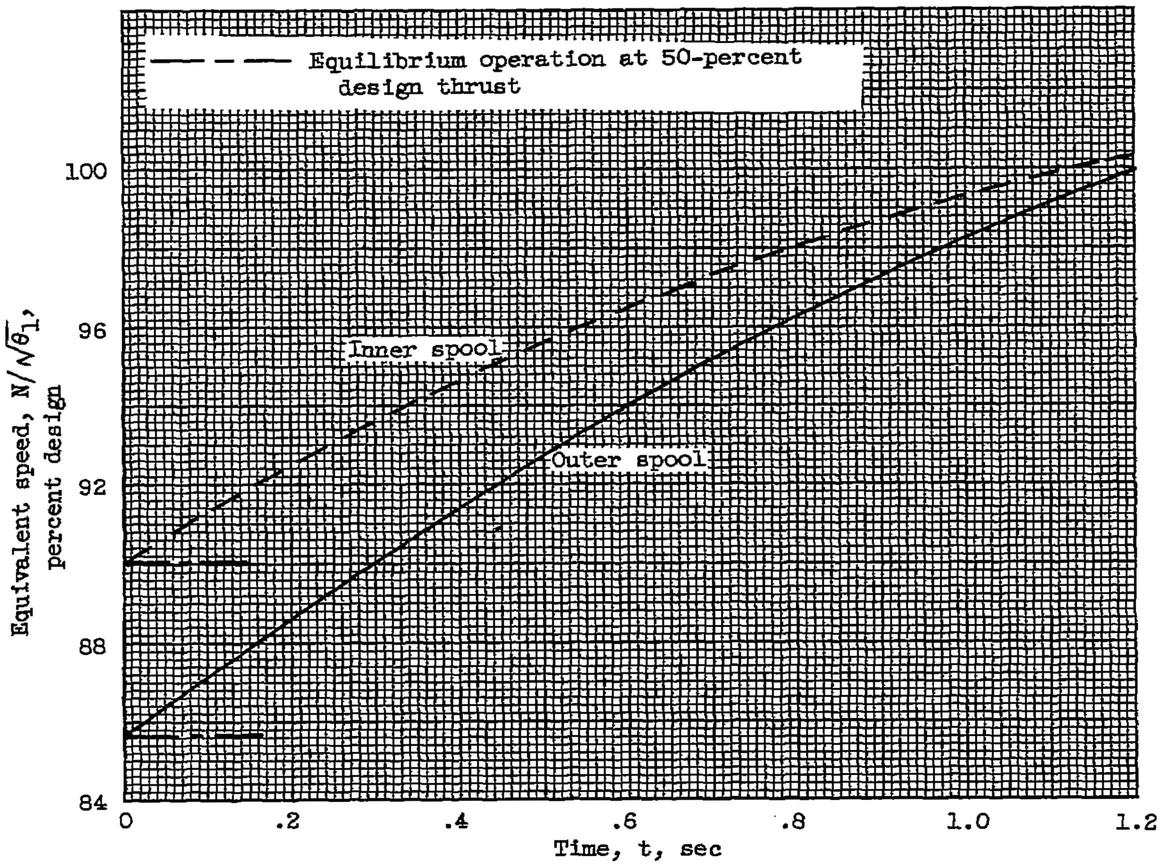
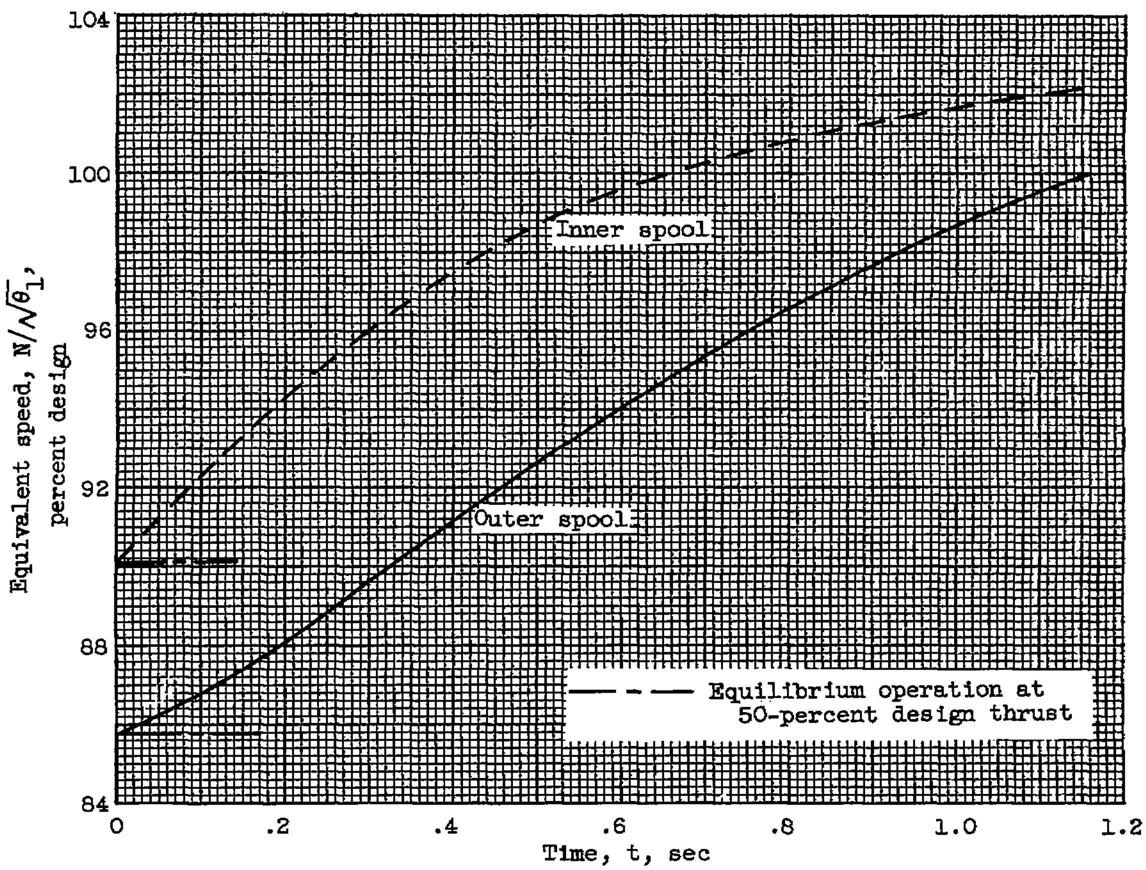


(a) Engine A.

Figure 3. - Variations during acceleration of outer- and inner-spool equivalent speeds with time.



(b) Engine B.

Figure 3. - Concluded. Variations during acceleration of outer- and inner-spool equivalent speeds with time.

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CO-4

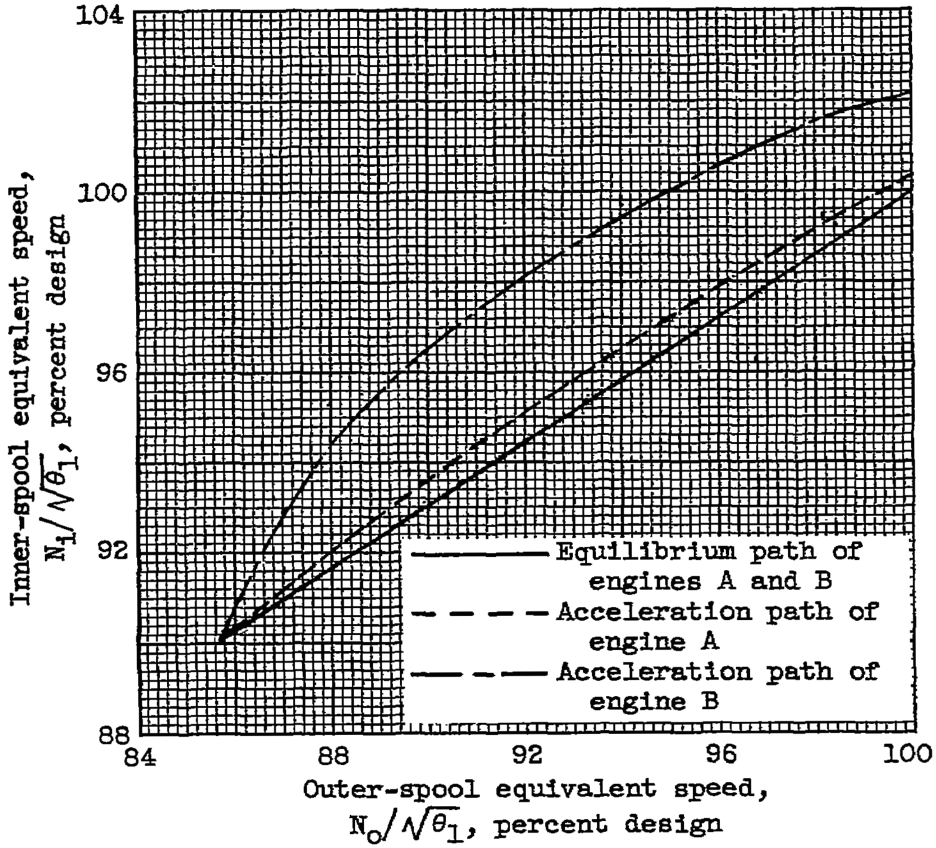
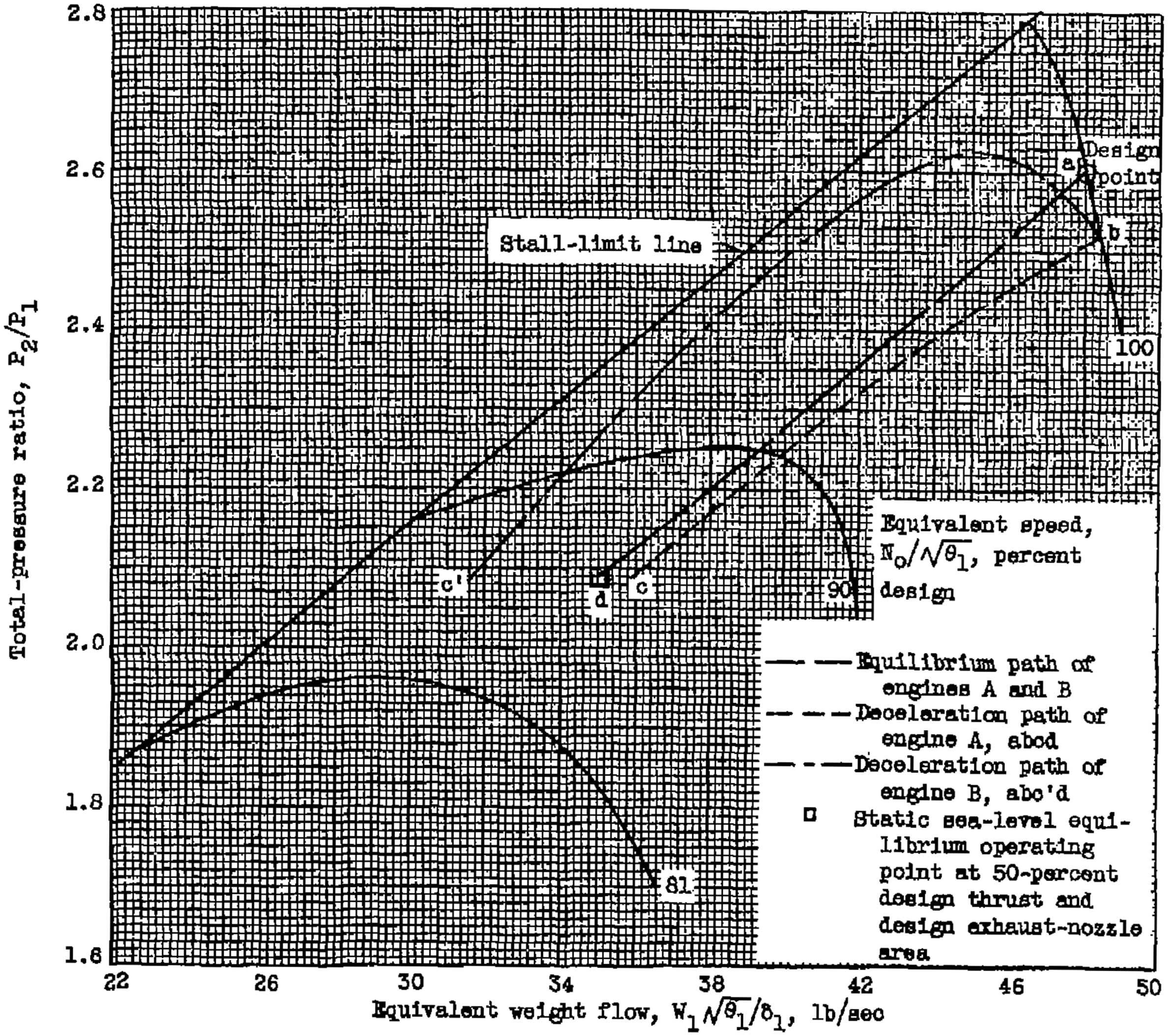


Figure 4. - Variation of inner-spool equivalent speed with outer-spool equivalent speed during acceleration.



(a) Outer compressor.

Figure 5. - Equilibrium and deceleration paths for engines A and B.

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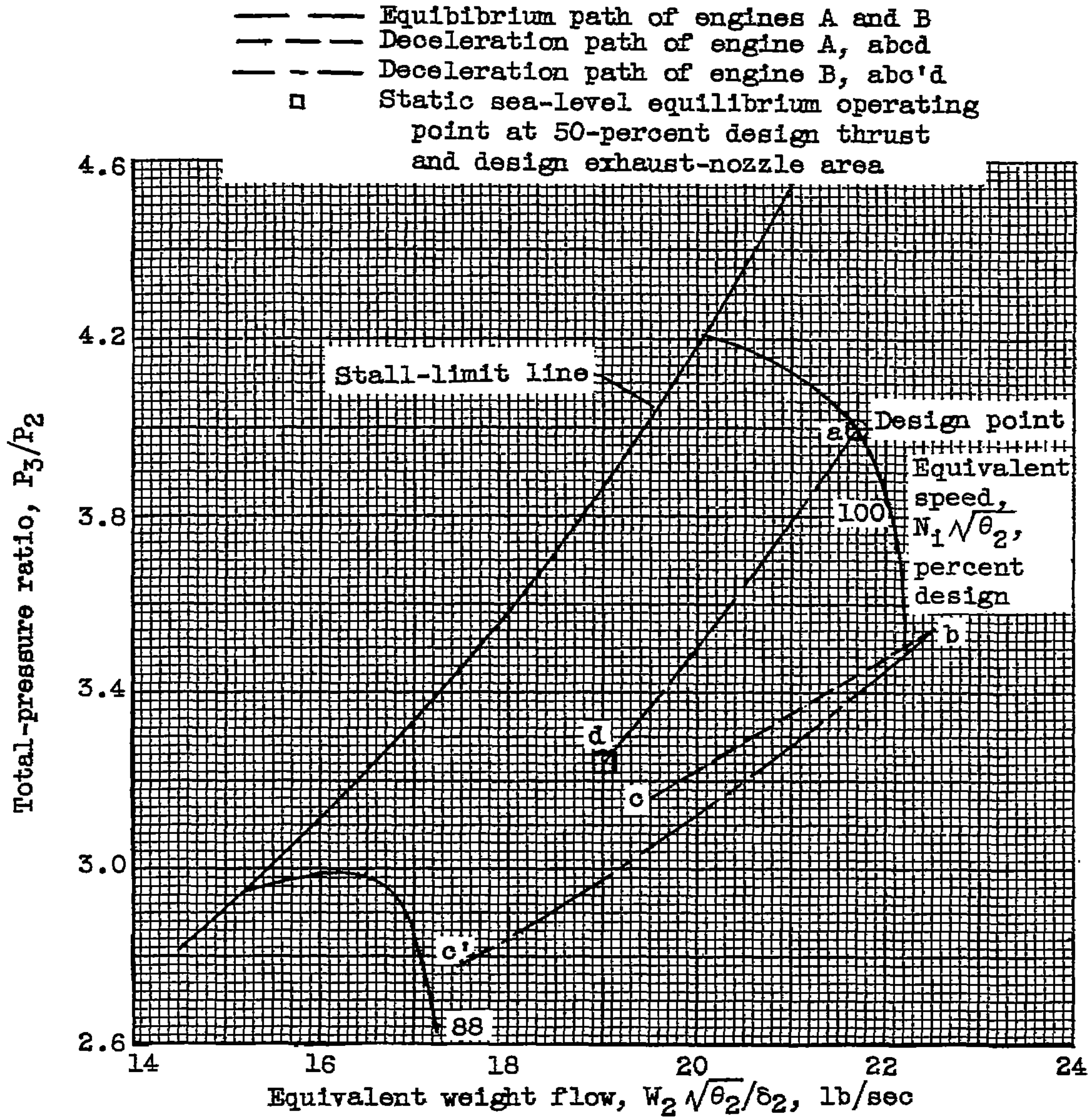
CO-4 back



(b) Inner compressor.

Figure 5. - Continued. Equilibrium and deceleration paths for engines A and B.

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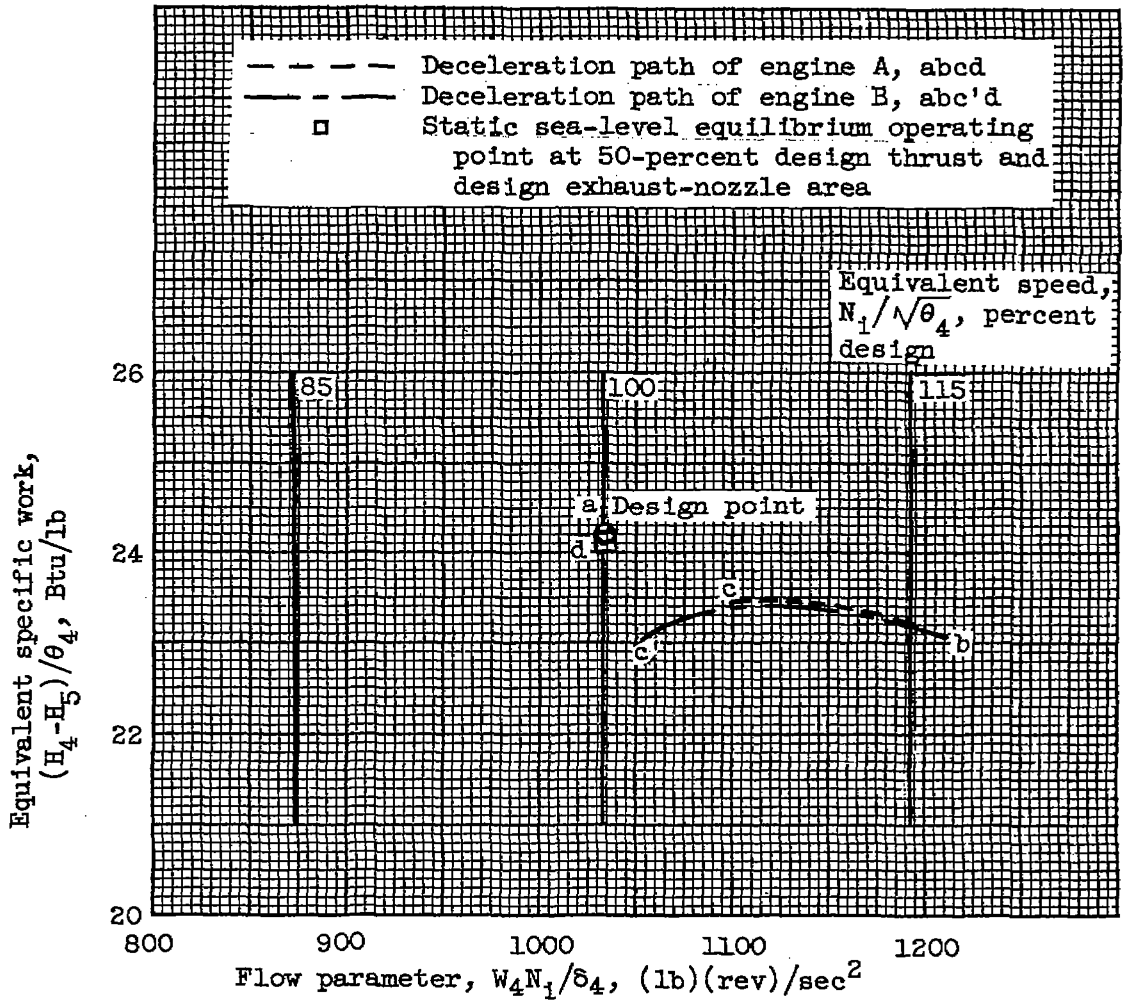

(c) Inner turbine.

Figure 5. - Continued. Equilibrium and deceleration paths for engines A and B.

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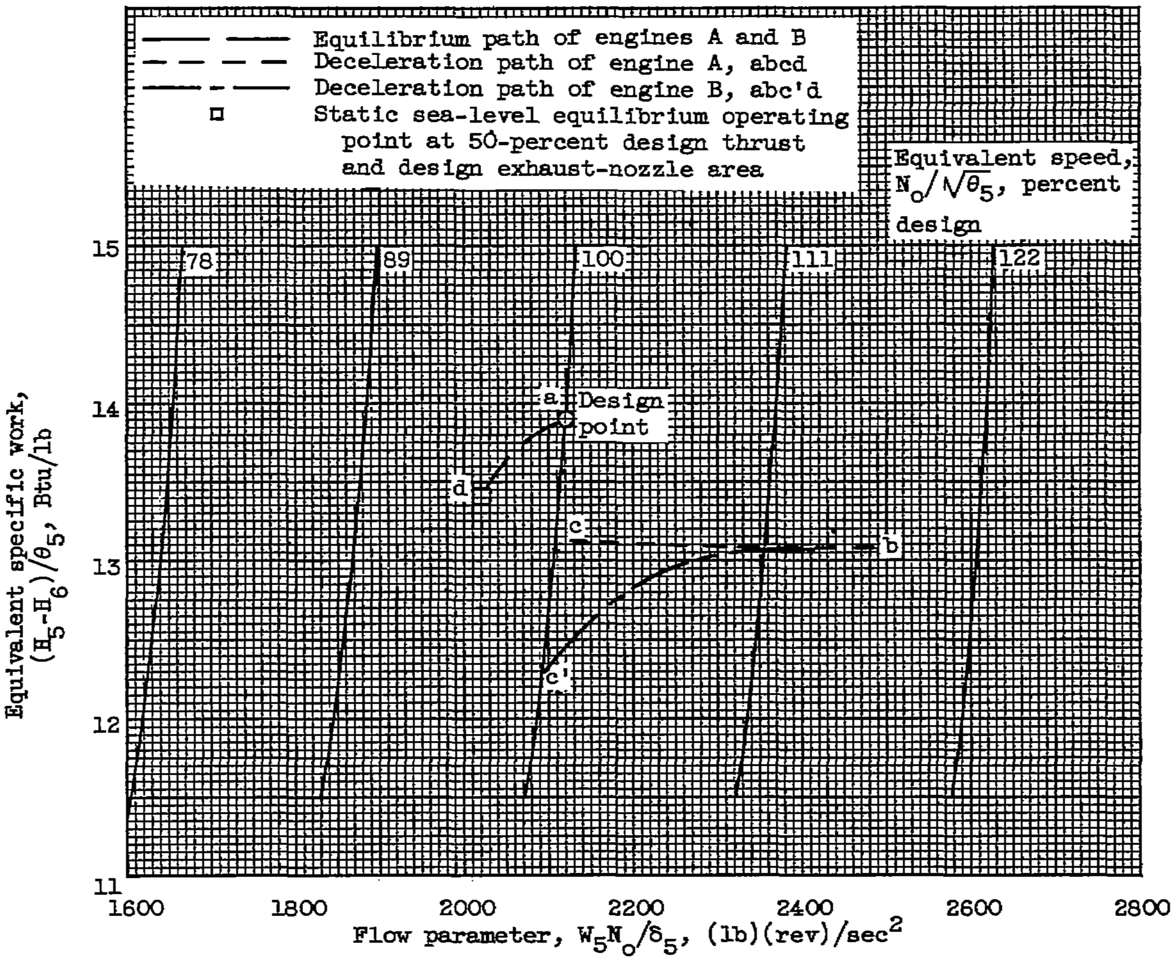

(d) Outer turbine.

Figure 5. - Concluded. Equilibrium and deceleration paths for engines A and B.

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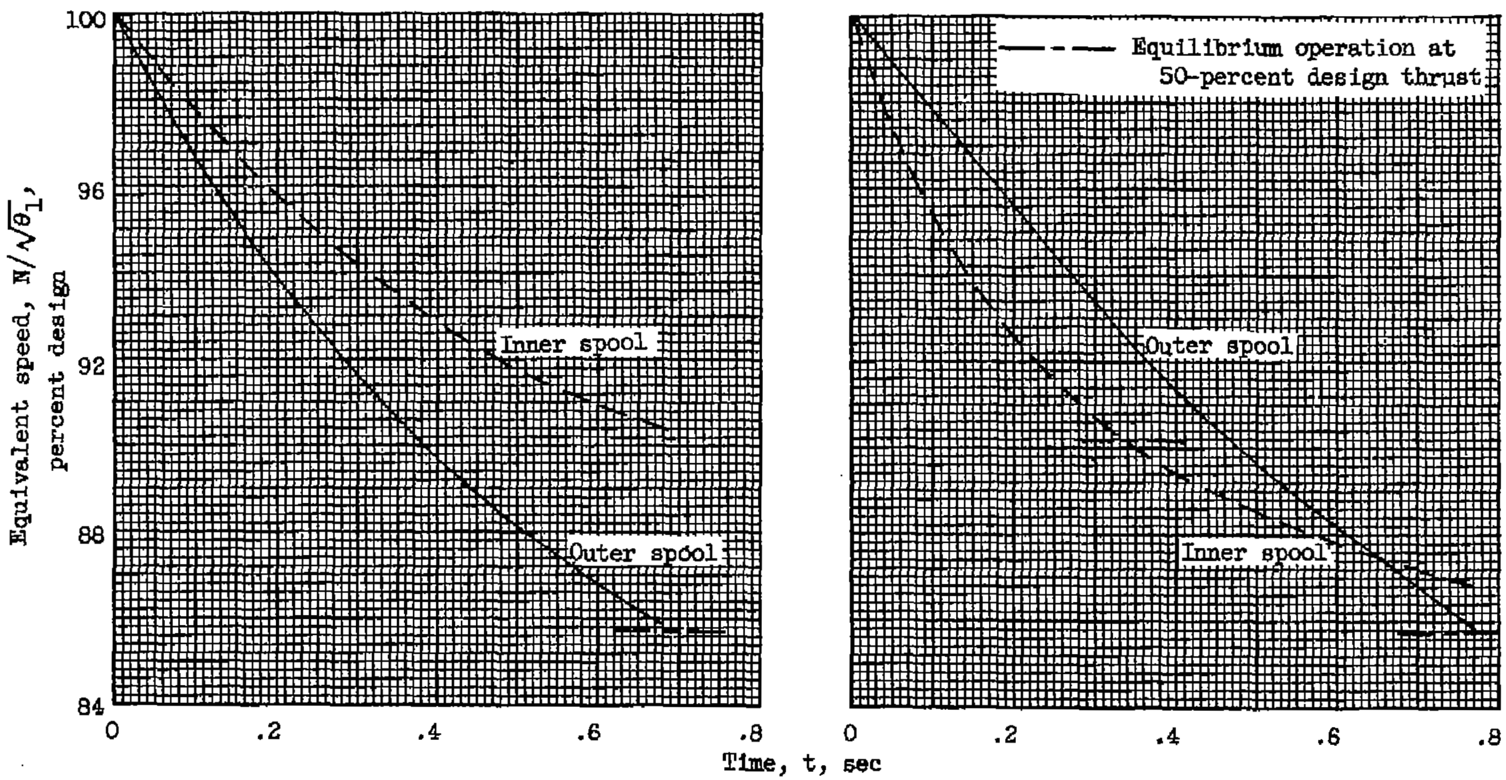

(a) Engine A.

(b) Engine B.

Figure 6. - Variations during deceleration of outer- and inner-spool equivalent speeds with time.

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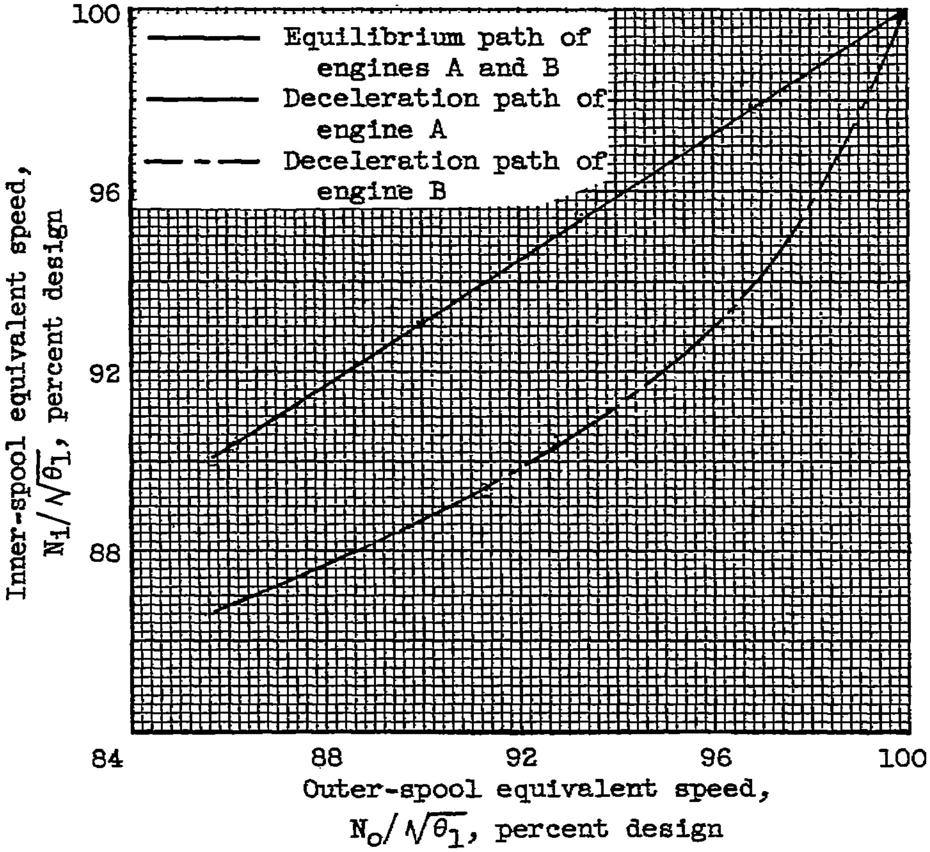

Figure 7. - Variation of inner-spool equivalent speed with outer-spool equivalent speed during deceleration.

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